# Estimation of PCB Dose Distributions for Three New York City Schools

## Using Measurement Data and the Stochastic Human Exposure and Dose Simulation (SHEDS) Model

**FINAL REPORT**
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## INTRODUCTION

On January 19, 2010, the City of New York and the New York City School Construction Authority (SCA) reached an agreement regarding the assessment and remediation of caulk containing PCBs in public school buildings with the United States Environmental Protection Agency (EPA), Region 2, under a Consent Agreement and Final Order (CAFO, Docket Number TSCA-02-2010-9201). The goal of the CAFO is to develop a city-wide approach to assessing and managing caulk containing PCBs in schools built between 1950 and 1978. As a result of the agreement, New York City initiated a comprehensive pilot study during the summer of 2010, when students were absent, to evaluate the possible presence of PCB-containing caulk and preferred remedial actions in three schools, with evaluations in two additional schools to be conducted in 2011.

A remedial investigation plan was developed by the SCA and TRC Engineers Inc. describing the selection of the pilot study schools, the approach for measuring PCBs in and around school buildings, and the caulk remediation approaches to be investigated (NYC SCA, 2010). Pre-remediation samples of caulk, indoor and outdoor air, indoor surface residues, and soils were collected in and around elementary schools P.S. 178, 199, and 309. Remedial remedies were then instituted at each school including caulk patch and repair (178X), caulk removal and replacement (199M), and caulk encapsulation (309K). Post-remediation indoor and outdoor air and indoor surface residue samples were collected to evaluate the remedial effect on PCB levels in the school environment.

Analysis of both the pre- and post-remediation air samples showed levels of PCBs at some indoor locations were greater than Public Health Levels recommended by the U.S. EPA (http://www.epa.gov/pcbsincaulk/maxconcentrations.pdf). Several actions were subsequently taken at the three schools to investigate and reduce the elevated PCB concentrations in air. In the first step, thorough cleaning was followed by a day of very high ventilation using multiple high-volume blowers, followed by collection of a set of additional air samples. Intensive examination of materials that could potentially serve as additional sources of PCBs was conducted. As part of this effort it was determined that PCB-containing fluorescent light ballasts were present throughout schools 199M and 309K, and in sections of school 178X. An additional set of air samples was collected at each school following removal of the PCB-containing light fixtures and a period of ventilation.

U.S. EPA Region 2 requested the assistance of EPA's National Exposure Research Laboratory (NERL), in the Office of Research and Development, in characterizing potential exposures associated with environmental levels of PCBs measured at the three New York City Schools. Region 2 specifically requested application of NERL's Stochastic Human Exposure and Dose Simulation (SHEDS) model for estimating multi-pathway exposure distributions. More information on SHEDS can be found at http://www.epa.gov/heasd/products/sheds_multimedia/sheds_mm.html and http://www.epa.gov/heasd/products/sheds_multimedia/files/SHEDS_related_publications.pdf.

NERL developed summary statistics for measurements at each time point within and across the three schools. No a-priori criteria were used to determine the suitability of the results for SHEDS modeling. Based on the quantity of measurements, percentage of measurements above the limit of detection, precision shown by duplicate sampling, and the distributions of measurement results, the data were judged to be suitable for SHEDS modeling across the three schools for the pre-remediation, post-remediation, post-ventilation, and post-light fixture removal time points. Estimated distributions of absorbed dose were developed for three age groups (6-10, 11-14, and 14-18 years old) at each time period. Estimates for the younger age group (6-10 years old) are most relevant for the three elementary schools for which PCB measurement data are available. Estimates were also prepared for the two older age groups to be informative should similar PCB levels be found to be present in middle and high schools. Estimates of the relative contribution of the inhalation, dermal, and non-dietary ingestion pathways to total exposures were also obtained via modeling.

Estimates derived from any modeling approach will involve some degree of uncertainty in the results. Uncertainties in this application of the SHEDS model may result from limitations in the school measurement data, model and exposure scenario assumptions, and limited information about several important model input parameters. There is insufficient information to fully estimate uncertainties in the modeled dose and exposure pathway contribution estimates at this time. Sensitivity testing was applied to two important but uncertain parameters – the fraction of PCBs absorbed through the lungs and the concentration of PCBs in dust, which was not measured by NYC. Additional data and time would be needed to conduct a more complete uncertainty analysis. It may be possible to fill some data gaps and reduce uncertainties through collection of additional data.

Included in this report are summary statistics for measurements at the three NYC schools, SHEDS model estimated absorbed dose distributions across the three schools at each time point (based on those measurements), estimates of the relative contribution of exposure pathways to modeled absorbed dose, examination of the impact of several successive mitigation actions on measured concentrations and modeled doses, and discussion of the limitations and uncertainties for these estimates. It is important to emphasize that the SHEDS dose estimates presented in this report are only those that might result from exposures at the schools and do not account for additional exposures from diet, residential, and ambient sources.

## SUMMARY AND CONCLUSIONS

Key results and conclusions are summarized for the school measurements and for the SHEDS modeling below. More detailed and additional information regarding the methods, results, and limitations are provided in subsequent sections of this report.

### School Measurements Summary

- A wide range of PCB concentrations were measured in caulk, air, surface wipe, and soil samples at New York City schools P.S. 178, P.S. 199, and P.S. 309.
- PCBs levels varied considerably within schools and between schools.
- Average PCB levels in indoor air decreased at P.S. 199 and P.S. 309 following each successive stage of remediation, including caulk remediation, increased ventilation, and removal of PCB-containing fluorescent light ballasts.
- Average PCB levels in indoor air were lower at P.S. 178 than at the other two schools; they increased slightly following caulk remediation and cleaning steps, but decreased with removal of PCB-containing fluorescent light ballasts.
- Building and room ventilation conditions were not well characterized; ventilation conditions and temperature varied across sampling dates; these variables likely impacted indoor air PCB concentrations to an undefined extent and may account for some of the observed differences between time points.
- Measurement data compiled across the three schools were judged to be adequate to support SHEDS modeling for pre-remediation, post-caulk remediation, post-ventilation/cleaning, and post-light fixture removal time points.

### SHEDS Model Dose Estimation Summary

- Using measurement data from three NYC schools as model inputs, distributions of estimated doses of total PCBs from the school environment were generated using the SHEDS model for three age groups (6–10, 11–13, and 14-18 years old).
- Distributions of estimated doses were generated separately for pre-remediation, post-caulk remediation, post-ventilation/cleaning, and post-light fixture removal time points.
- Estimates of absorbed dose in this analysis include only those exposures resulting from the school environment. Distributions of dietary intake of PCBs and exposure to PCBs in non-school environments for use in the SHEDS model have not been generated at this time.
- Estimated doses for 6–10 year-olds at the pre-remediation time point were 0.022 µg/kg/day at the 50$^{th}$ percentile and 0.030 µg/kg/day at the 95$^{th}$ percentile of the distribution.
- Estimated doses for 6–10 year-olds were greater than those for 11–13 year olds, which were greater than those for 14–18 year olds.
- Estimated doses decreased at each of the three successive post-remediation time points.
- At the post-light fixture removal time point, estimated doses for 6–10 year-olds decreased to 0.007 µg/kg/day at the 50$^{th}$ percentile and 0.010 µg/kg/day at the

95th percentile. These levels were approximately 3-fold lower than those at the pre-remediation time point.

- The overall decrease in estimated doses likely reflects the cumulative effect of efforts to reduce indoor air PCB levels across the remediation steps, particularly at schools P.S. 199 and P.S. 309.
- The predominant route of exposure for all age groups at all time points would be via inhalation; it was estimated that, on average, over 90% of the dose would result from inhalation at the pre-remediation time point and over 80% was from inhalation at the post-light fixture removal time point.
- As described in more detail in the final section, there are uncertainties and limitations in modeled estimates of dose distributions and contributions of relative exposure pathways.
- Limited sensitivity analysis showed that the estimated doses were moderately sensitive to assumptions about PCB concentration in dust, but were somewhat more sensitive to assumptions regarding the absorbed fraction in the lung.
- Because a majority of the dose would likely be from inhalation exposures, and because the PCB dose estimates are sensitive to input inhalation absorption factors, future research could refine the SHEDS inhalation dose algorithm or link to a PBPK model developed for PCBs.

## SCHOOL CONDITIONS AND MEASUREMENT RESULTS

It is important to understand the sampling design, school conditions, and the sample measurement results with regard to SHEDS dose modeling. This information is described below.

As part of the New York City pilot project, samples were collected and remedial activities were undertaken at three schools during the summer of 2010. The approach and methods for the sampling design, sample collection, and sample analysis were described in the Remedial Investigation Plan (NYC SCA, 2010). Briefly, a set of samples was to be collected inside and outside of three school buildings prior to caulk remediation activities. These samples included caulk, indoor and outdoor air, surface wipes from high contact (desks/tables) and low contact (floors/walls/windowsills) surfaces, and soil from multiple distances near the school building. Samples were collected from pre-selected classrooms, cafeterias, gymnasiums, libraries, and transitional spaces such as hallways, stairways, and lobbies. Sampling locations were not selected based on known or suspected PCB sources; rather, they were selected to provide a broad sampling of locations where school children would be likely to spend time during the day. No dust samples were included in the measurement design. Following the pre-remediation sampling, the PCB-containing caulk was remediated using a different approach at each school. These approaches included removal, patch and repair, and encapsulation. Another set of indoor and outdoor air and surface wipe samples were collected following completion of caulk remediation to assess the impact of the remediation on PCB levels in the school environments.

Analysis of the pre- and post-remediation air samples showed levels of PCBs at some indoor locations were greater than Public Health Levels recommended by the U.S. EPA. Several actions were subsequently taken by the NYC SCA to investigate and reduce the elevated PCB concentrations in air. In the first step, thorough cleaning was followed by a day of very high ventilation using multiple high-volume blowers, followed by collection of a set of additional air samples. Intensive examination of materials that could potentially serve as sources of PCBs was conducted at schools 199M and 309K, where numerous bulk samples of paints, tiles, mastics, mastics and other materials were collected for analysis. As part of this effort it was determined that PCB-containing fluorescent light ballasts were present throughout schools 199M and 309K, and in sections of school 178X. An additional set of air samples was collected at each school following removal of the PCB-containing light fixtures and a period of ventilation. Subsequent activities at schools 178X and 199M included supplemental cleaning and the adjustment of HVAC systems.

Conditions at the three schools for the four time periods subsequently selected for SHEDS dose modeling analysis are shown in Table 1. The encapsulation or supplemental cleaning and HVAC adjustment time periods at schools 178X and 199M were not included in SHEDS modeling because of the small number of samples and because the activities were not performed across all three schools. Sample collections occurred following each of the remedial activities described in Table 1. Samples were collected on different days and often under different conditions of ventilation. Ventilation rates are an important factor for the concentration of pollutants in indoor air. Ventilation rates in each sampled room were not measured at each of the pre-remediation, post-caulk remediation, post-ventilation time point, and were assessed in PS 199 only after light fixture removal. Thus, it is difficult to disentangle the combined impact of remediation and ventilation differences on the PCB air concentrations for individual rooms at a school and between schools.

The types and numbers of samples collected at each time point are described in Table 2. Caulk samples were collected approximately one month prior to collection of the environmental samples to help define the caulk needing remediation. Several different types of caulk or window glaze were often collected from each room or transitional space. The number of indoor air samples shows the total number of rooms and transitional spaces sampled at each time. Air and surface wipe samples were collected from the same rooms and transitional spaces at the pre-remediation and post-caulk remediation time points. A second set of pre-remediation air samples was collected at school 309K on a different day. Air samples were collected in most of the same locations across the pre-remediation, post-remediation, and post-ventilation time points. Many additional indoor spaces were included for indoor air PCB measurement at the post-light fixture removal time point, and several additional indoor spaces were sampled in school 178X at the post-ventilation time point.

Table 1. Measurement time points and school conditions.

| School/Time point | Condition | Ventilation |
|---|---|---|
| **School 178X** | | |
| Pre-Remediation | Prior to caulk remediation | Windows closed; HVAC on in non-tested areas, off in tested areas |
| Post-Remediation | After PCB caulk patch and repair | Windows closed; HVAC on in non-tested areas, off in tested areas |
| Post-Cleaning | After pre-K, K, and special education classrooms thoroughly cleaned | HVAC system on (one air intake found to be inadvertently closed during testing) |
| Post-Light Fixture Removal | After PCB-ballast/fixture removal in pre-K, K, and special education classrooms | HVAC system on (one air intake found to be inadvertently closed during testing) |
| **School 199M** | | |
| Pre-Remediation | Prior to caulk remediation | Windows closed; internal ventilation system on |
| Post-Remediation | After PCB caulk removal | Windows closed; internal ventilation system on |
| Post-Ventilation | After school thoroughly cleaned; after 24 hours high ventilation | Windows open; internal ventilation system on |
| Post-Light Fixture Removal | After PCB-ballast/fixture removal throughout building | Windows open; internal ventilation system on; window AC units off |
| **School 309K** | | |
| Pre-Remediation (initial sampling) | Prior to caulk remediation | Windows closed; internal ventilation system on |
| Pre-Remediation (second sampling) | Prior to caulk remediation; re-sampling due to high levels in initial sampling | Windows closed; internal ventilation system on |
| Post-Remediation | After PCB caulk encapsulation | Windows closed; internal ventilation system on |
| Post-Ventilation | After school thoroughly cleaned; after high ventilation for 24 hours | Windows open; internal ventilation system on |
| Post-Light Fixture Removal | After PCB-ballast/fixture removal throughout building | Windows open; internal ventilation system on; window AC units off |

Table 2. Number of samples collected for PCB measurement at each time point.

| School/Time point | Caulk and Window Glaze Samples | Indoor Air Samples | Outdoor Air Samples | High-Contact Surface Wipe Samples | Low-Contact Surface Wipe Samples | Soil Samples |
|---|---|---|---|---|---|---|
| **School 178X** | | | | | | |
| Pre-Remediation | 80 | 11 (+ 1 dup) | 1 | 11 | 11 | 100 (+ 6 dup) |
| Post-Remediation | - | 11 (+ 1 dup) | - | 11 | 11 | - |
| Post-Cleaning | - | 15 (+ 1 dup) | 1 | - | - | - |
| Post-Light Fixture Removal | - | 16 (+ 1 dup) | 1 | - | - | - |
| **School 199M** | | | | | | |
| Pre-Remediation | 78 | 12 (+ 1 dup) | 1 | 12 | 12 | 88 (+ 5 dup) |
| Post-Remediation | - | 12 (+ 1 dup) | 1 | 12 | 20 | - |
| Post-Ventilation | - | 12 (+ 1 dup) | - | - | - | - |
| Post-Light Fixture Removal | - | 59 (+ 3 dup) | - | - | - | - |
| **School 309K** | | | | | | |
| Pre-Remediation (initial sampling) | 99 | 14 (+ 1 dup) | 1 | 14 | 14 | 30 (+ 2 dup) |
| Pre-Remediation (second sampling) | - | 11 (+ 1 dup) | 1 | 14 | 14 | - |
| Post-Remediation | - | 14 (+ 1 dup) | 1 | - | - | - |
| Post-Ventilation | - | 14 (+ 1 dup) | 1 | - | - | - |
| Post-Light Fixture Removal | - | 68 (+ 3 dup) | - | - | - | - |

**Statistical Summarization of Measurements**
Measurement results and additional information were provided by the NYC SCA and TRC Engineers, Inc. to the U.S. EPA Region 2. The results and information were subsequently provided by Region 2 to the U.S. EPA Office of Research and Development, National Exposure Research Laboratory. Measurement results for air, surface wipe, and dust were compiled to develop PCB concentration distributions for use in SHEDS modeling.

Caulk and window glaze samples were collected in advance of the collection of school environmental samples. A summary of the measurement results across all three schools, and for each individual school, is shown in Table 3. Results are reported as total PCBs in ppm (mg/kg). Aroclors 1248, 1254, and 1260 were most often reported for the caulk samples, and often a combination of Aroclors was reported for individual samples. As shown in Table 4, only 17.5% of the caulk and glaze samples had concentrations above 50 ppm (EPA regulations implementing the Toxic Substances Control Act prohibit the use of PCBs at levels above 50 ppm), while 6.2% had total PCB levels above 100,000 ppm. Caulk and window glaze measurement results were not used in the SHEDS modeling because of the lack of information regarding direct contact with caulk or ingestion of caulk particles, but are reported here to provide a more thorough understanding of conditions at the schools.

Indoor air measurement results are summarized in Table 5 as total PCBs across all three schools, and for each individual school. Total PCB measurements were based on analysis of PCBs as Aroclors in air. A combination of Aroclors 1248 and 1254 were reported most often for indoor air samples. Exterior samples of ambient air were collected outside of the schools for many of the time periods. All outdoor air measurements were below the detection limits (ranging from about 44 to 52 ng/m$^3$ for this study). Duplicate samples were collected side-by-side with a subset of air and soil samples for quality control purposes. When duplicate samples were collected, the measurement results for the collocated samples were averaged and the average value used in the statistics and SHEDS modeling. When the measurement result was reported as not detected (that is, below the analytical detection limit) a value of one-half of the reported detection limit was substituted for statistical summarization and for SHEDS analysis.

Indoor air total PCB concentration distributions are graphically presented in Figure 1. Across the combined data from all three schools, and for schools 199M and 309K individually, the indoor air concentrations decreased for each subsequent remediation time point. Indoor air levels at school 178X were lower than those at the other two schools and showed a different pattern of changes at the different sample time points. The relative impact of variable ventilation rates on some of the observed differences cannot be discerned, but could explain some of the changes observed between certain time points such as those at school 178X.

Table 3. Summary of Caulk and Window Glaze Results at Three NYC Schools (ppm)[a,b]

| School | N | N > DL[c] | Median ppm | Mean ± S.D. ppm | Range ppm |
|---|---|---|---|---|---|
| All Three Schools Combined | 257 | 220 | 9.5 | 15,600 ± 58,700 | ND[d] – 440,000 |
| School 178X | 80 | 49 | 1.9 | 2,600 ± 14,000 | ND – 90,700 |
| School 199M | 78 | 76 | 24 | 17,400 ± 50,000 | ND – 243,000 |
| School 309K | 99 | 95 | 9.7 | 24,700 ± 81,600 | ND – 440,000 |

[a] Reported as total PCBs from Aroclor measurements in caulk.
[b] All samples collected prior to any 2010 remediation.
[c] Number with measurement results greater than the detection limit (the DL was variable depending on amount of caulk analyzed and ranged from 0.33 to 79.4 ppm; the DL for most caulks with low or non-detect values was < 3 ppm.).
[d] Not detected.

Table 4. Caulk and Window Glaze Results Above Specified Levels[a]

| | All Three Schools Combined | School 178X | School 199M | School 309K |
|---|---|---|---|---|
| | | *Number of Samples* | | |
| All samples | 257 | 80 | 78 | 99 |
| 50 – 999 ppm | 20 | 8 | 12 | 0 |
| 1000 – 9,999 ppm | 3 | 2 | 0 | 1 |
| 10,000 – 99,000 ppm | 6 | 3 | 3 | 0 |
| > 100,000 ppm | 16 | 0 | 7 | 9 |
| | | *Percentage of Samples* | | |
| 50 – 999 ppm | 7.8 | 10 | 15 | 0 |
| 1000 – 9,999 ppm | 1.2 | 2.5 | 0 | 1.0 |
| 10,000 – 99,000 ppm | 2.3 | 3.8 | 3.8 | 0 |
| > 100,000 ppm | 6.2 | 0 | 9.0 | 9.1 |

[a] EPA regulations implementing the Toxic Substances Control Act (TSCA) prohibit the use of PCBs at levels above 50 ppm.

Table 5. Summary of Indoor Air Measurement Results at Three NYC Schools ($ng/m^3$)[a,b,c]

| School/Time point | N | N > DL[e] | Median $ng/m^3$ | Mean ± S.D. $ng/m^3$ | Range $ng/m^3$ |
|---|---|---|---|---|---|
| **All Three Schools Combined** | | | | | |
| Pre-Remediation[d] | 37 | 32 | 496 | 596 ± 586 | ND[f] - 2920 |
| Post-Remediation | 37 | 36 | 328 | 428 ± 359 | ND - 1740 |
| Post-Ventilation | 41 | 39 | 203 | 237 ± 160 | ND - 631 |
| Post-Light Fixture Removal | 143 | 86 | 76 | 123 ± 101 | ND - 362 |
| **School 178X** | | | | | |
| Pre-Remediation | 11 | 6 | 58 | 76 ± 62 | ND - 195 |
| Post-Remediation | 11 | 10 | 159 | 150 ± 92 | ND - 328 |
| Post-Cleaning | 15 | 13 | 124 | 145 ± 103 | ND - 382 |
| Post-Light Fixture Removal | 16 | 9 | 54 | 75 ± 66 | ND - 227 |
| Post-Supplemental Cleaning | 5 | 5 | 146 | 196 ± 158 | 53 - 429 |
| Post-HVAC Adjustment | 3 | 0 | ND | ND | ND |
| **School 199M** | | | | | |
| Pre-Remediation | 12 | 12 | 807 | 838 ± 306 | 414 – 1460 |
| Post-Remediation | 12 | 12 | 516 | 531 ± 193 | 245 - 934 |
| Post-Ventilation | 12 | 12 | 438 | 438 ± 113 | 275 – 631 |
| Post-Light Fixture Removal | 59 | 58 | 224 | 222 ± 58 | ND – 362 |
| Post-Encapsulation | 10 | 10 | 422 | 437 ± 75 | 354 - 599 |
| Post-HVAC Adjustment | 10 | 10 | 185 | 195 ± 24 | 162 - 231 |
| **School 309K** | | | | | |
| Pre-Remediation (Day 1) | 14 | 14 | 504 | 796 ± 737 | 236 - 2920 |
| Pre-Remediation (Day 2) | 11 | 11 | 949 | 1240 ± 1280 | 396 - 4960 |
| Post-Remediation | 14 | 14 | 380 | 557 ± 474 | 165 - 1740 |
| Post-Ventilation | 14 | 14 | 180 | 163 ± 58 | 53 - 230 |
| Post-Light Fixture Removal | 68 | 19 | ND | 48 ± 54 | ND - 331 |

[a] Reported as total PCBs from Aroclor measurements in indoor air.
[b] One-half the limit of detection was substituted for values less than the limit of detection.
[c] When duplicate samples were collected, the average of the duplicates was used.
[d] Does not include Day 2 pre-remediation results for school 309K.
[e] Number with measurement results greater than the detection limit (DL was in the range of 44 to 52 $ng/m^3$ for most samples).
[f] Not detected.

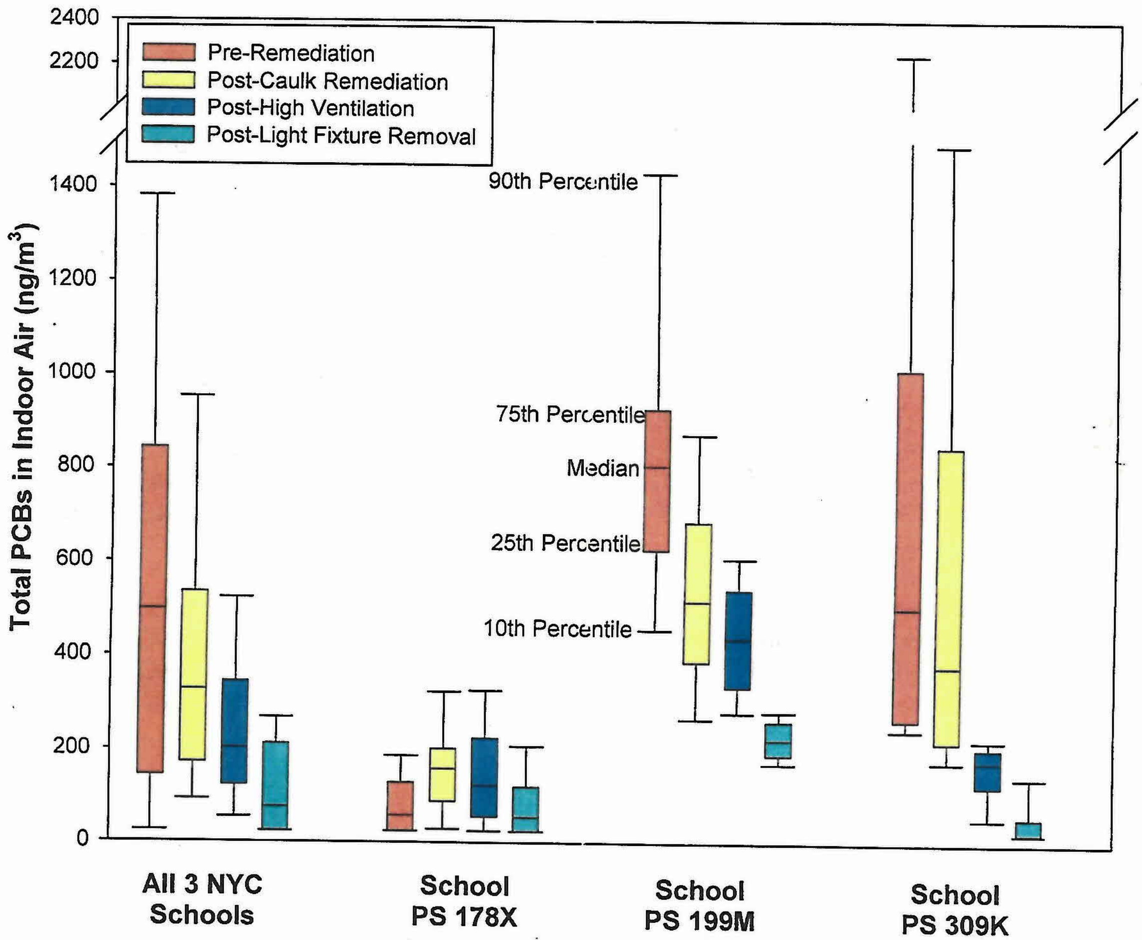



Figure 1. Summary of indoor air PCB measurement distributions at three NYC schools (post-supplemental cleaning and post-HVAC adjustment results not shown due to small numbers of samples).

Indoor surface wipe measurement results are summarized as total PCBs in Table 6 across all three schools, and for each individual school. In each building space separate wipes of high contact (tables/desks) and low contact (floors/walls/window sills) were collected. Samples were collected prior to the caulk remediation, and then again in the same building locations following the caulk remediation. Aroclor 1254 was most often reported for surface wipe samples. Measurement results exceeded 1 μg/100 $cm^2$ in only one sample – a value of 97.6 μg/100 $cm^2$ in the gymnasium at school 199M. An additional eight low contact samples were collected in the gymnasium room and all had levels below 0.21 μg/100 $cm^2$. Results for nine samples collected at that location were averaged into one result for the gymnasium that was then included in the statistical summary and SHEDS analysis.

Table 6. Summary of Surface Wipe Measurement Results at Three NYC Schools ($\mu g/100\ cm^2$)[a,b]

| School/Time point | N | N > DL[c] | Median µg/100 $cm^2$ | Mean ± S.D. µg/100 $cm^2$ | Range µg/100 $cm^2$ |
|---|---|---|---|---|---|
| **All Three Schools Combined** | | | | | |
| Pre-Remediation – High Contact | 37 | 24 | 0.14 | 0.18 ± 0.18 | ND[d] – 0.75 |
| Post-Remediation – High Contact | 37 | 18 | ND | 0.16 ± 0.20 | ND – 0.95 |
| Pre-Remediation – Low Contact | 37 | 27 | 0.16 | 0.24 ± 0.21 | ND – 0.86 |
| Post-Remediation – Low Contact | 37 | 23 | 0.14 | 0.47 ± 1.78 | ND – 11.0[e] |
| **School 178X** | | | | | |
| Pre-Remediation – High Contact | 11 | 6 | 0.11 | 0.10 ± 0.05 | ND – 0.18 |
| Post-Remediation – High Contact | 11 | 1 | ND | 0.06 ± 0.04 | ND – 0.18 |
| Pre-Remediation – Low Contact | 11 | 5 | ND | 0.16 ± 0.21 | ND - 0.72 |
| Post-Remediation – Low Contact | 11 | 6 | 0.13 | 0.16 ± 0.15 | ND – 0.54 |
| **School 199M** | | | | | |
| Pre-Remediation – High Contact | 12 | 10 | 0.21 | 0.29 ± 0.25 | ND – 0.75 |
| Post-Remediation – High Contact | 12 | 9 | 0.13 | 0.19 ± 0.21 | ND – 0.81 |
| Pre-Remediation – Low Contact | 12 | 10 | 0.16 | 0.24 ± 0.17 | ND - 0.57 |
| Post-Remediation – Low Contact | 12 | 11 | 0.19 | 1.09 ± 3.11 | ND – 11.0[e] |
| **School 309K** | | | | | |
| Pre-Remediation – High Contact | 14 | 8 | 0.15 | 0.16 ± 0.12 | ND – 0.40 |
| Post-Remediation – High Contact | 14 | 8 | 0.13 | 0.21 ± 0.24 | ND – 0.95 |
| Pre-Remediation – Low Contact | 14 | 12 | 0.21 | 0.30 ± 0.25 | ND – 0.86 |
| Post-Remediation – Low Contact | 14 | 6 | ND | 0.19 ± 0.22 | ND – 0.75 |

[a] Reported as total PCBs from Aroclor measurements in wipe samples.
[b] One-half the limit of detection was substituted for values less than the limit of detection.
[c] Number with measurement results greater than the detection limit (DL = 0.10 µg/100 $cm^2$).
[d] Not detected.
[e] A wipe sample with an elevated PCB level (97.6 µg/100 $cm^2$) was collected from the gymnasium at school 199M. Eight other low-contact samples were also collected from the gym with results ranging from not detected to 0.202 µg/100 $cm^2$. An average of the nine results (10.97 µg/100 $cm^2$) was used to generate a single result for the gymnasium that was then used in the statistics and modeling.

Outdoor soil sample measurement results (used for modeling dose from soil and dust ingestion) are summarized as total PCBs in Table 7 across all three schools, and for each individual school. Samples were collected from multiple locations around each school building. At many locations, samples were collected from points at two or three distances from the structure. Samples at school 178X were collected from two different depths. Aroclor 1254 was reported for all soil samples with levels above the detection limit. At schools 178X and 309K, the concentrations of PCBs in soil tended to decrease with distance from the building. Most of the soil samples from school 199M had not-detected results. While all of the soil measurement results are shown in Table 7, only the soil samples collected at the 0 – 2" depth were used for SHEDS modeling.

Table 7. Summary of Soil Measurement Results at Three NYC Schools (ppm)[a,b,c]

| School and Soil Distance/Depth | N | N > DL[e] | Median ppm | Mean ± S.D. ppm | Range ppm |
|---|---|---|---|---|---|
| **All Three Schools Combined** | | | | | |
| 0.5' from building; 0 – 2" soil depth | 51 | 16 | ND[f] | 6.89 ± 29.7 | ND – 211 |
| 0.5' from building; 2 – 4" soil depth[d] | 12 | 7 | 1.43 | 3.89 ± 5.57 | ND – 19.4 |
| 3' from building; 0 – 2" soil depth | 51 | 12 | ND | 1.72 ± 3.68 | ND – 20.6 |
| 3' from building; 2 – 4" soil depth | 12 | 7 | 0.79 | 1.49 ± 1.99 | ND – 7.00 |
| 8' from building; 0 – 2" soil depth | 66 | 18 | ND | 0.75 ± 1.00 | ND – 5.28 |
| 8' from building; 2 – 4" soil depth | 26 | 2 | ND | 0.29 ± 0.11 | ND – 0.66 |
| All samples | 218 | 62 | ND | 2.57 ± 14.7 | ND - 211 |
| **School 178X** | | | | | |
| 0.5' from building; 0 – 2" soil depth | 12 | 5 | 0.91 | 20.0 ± 60.3 | ND – 211 |
| 0.5' from building; 2 – 4" soil depth | 12 | 7 | 1.43 | 3.89 ± 5.57 | ND – 19.4 |
| 3' from building; 0 – 2" soil depth | 12 | 1 | ND | 0.62 ± 1.30 | ND – 4.74 |
| 3' from building; 2 – 4" soil depth | 12 | 7 | 0.79 | 1.49 ± 1.99 | ND – 7.00 |
| 8' from building; 0 – 2" soil depth | 26 | 2 | ND | 0.33 ± 0.25 | ND – 1.39 |
| 8' from building; 2 – 4" soil depth | 26 | 2 | ND | 0.29 ± 0.11 | ND – 0.66 |
| **School 199M** | | | | | |
| 0.5' from building; 0 – 2" soil depth | 31 | 3 | ND | 0.31 ± 0.17 | ND – 1.03 |
| 3' from building; 0 – 2" soil depth | 30 | 2 | ND | 0.32 ± 0.25 | ND – 1.34 |
| 8' from building; 0 – 2" soil depth | 27 | 3 | ND | 0.40 ± 0.49 | ND – 2.48 |
| **School 309K** | | | | | |
| 0.5' from building; 0 – 2" soil depth | 8 | 8 | 9.60 | 12.7 ± 9.14 | 5.70 – 32.7 |
| 3' from building; 0 – 2" soil depth | 9 | 9 | 5.84 | 7.88 ± 5.51 | 2.31 – 20.6 |
| 8' from building; 0 – 2" soil depth | 13 | 13 | 2.10 | 2.33 ± 1.19 | 0.78 – 5.28 |

[a] Reported as total PCBs from Aroclor measurements in soil samples.
[b] One-half the limit of detection was substituted for values less than the limit of detection.
[c] When duplicate samples were collected, average of duplicates used.
[d] Samples collected in 2 – 4" depth range only at school 178X.
[e] Number with measurement results greater than the detection limit (DL = 0.5 ppm for most samples).
[f] Not detected.

## SHEDS METHOD AND INPUTS

### SHEDS Background Information

SHEDS-Residential is one of modules of the SHEDS-Multimedia model (http://www.epa.gov/heasd/products/sheds_multimedia/files/SHEDS_Residentialv4_Techmanual_06-16-2010.Final.pdf; Glen et al., 2010). The primary function of the SHEDS-residential model is to estimate the exposure of a population to one or more specified chemicals from inhalation, ingestion (by mouthing of hands or objects), or dermal contact in a residential setting. SHEDS uses the Monte Carlo statistical method to simulate a population of individuals based on time-location-activity diaries in EPA's Consolidated Human Activity Database (CHAD; www.epa.gov/chadnet1) and weights from the U.S. Census. These individuals are not specific persons, but are stochastically created synthetic persons whose collective properties reflect the simulated population and input distributions for exposure-related variables. For each individual, SHEDS constructs a sequence of activities, media concentrations, and the resulting exposures over the selected simulation period, which may range from one day to a year or more (although simulation time steps can range from 1 minute to 1 hour within a day). These individual exposure time series may be stored or exported, or aggregated over time to give time-integrated or time-averaged exposures (Figure 2). They may also be input to a dose model, either internal or external to SHEDS, to follow the fate of the chemical after it enters the human body. Exposure is defined in this model as the contact between a chemical agent and a simulated human target at the external body surface, either the skin surface or the oral/nasal boundary. Dose is defined in this model as the amount of chemical that enters the target after crossing the exposure surfaces. Details regarding the pathways, distributional functions, and exposure/dose equations are provided in the SHEDS Technical Manual (Glen et al., 2010).

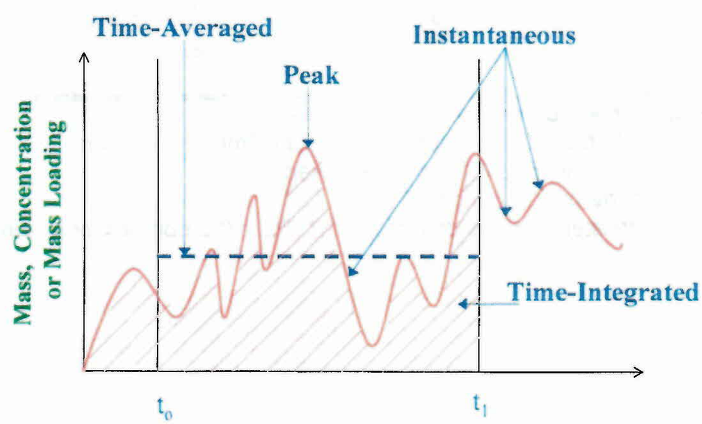



Figure 2. Hypothetical exposure profile for an individual.

SHEDS can be used for various purposes, including estimating population distributions of exposure and dose; understanding intensity, duration, frequency, and timing of exposures; identifying critical media, exposure routes, and factors; considering how to identify and address greatest uncertainties; and comparing modeled estimates against real-world data. Figures 3 and 4 illustrate the SHEDS methodology. The model estimates the exposure and/or dose of individuals in a user-specified population cohort to a particular chemical via three primary exposure routes: inhalation, non-dietary ingestion (i.e., via soil/dust ingestion, hand mouthing, or object mouthing pathways), and dermal contact in a residential setting. To do this, it simulates the daily activities and locations of individuals using sequential time/location/activity diaries from EPA's Consolidated Human Activity Database (CHAD) (McCurdy et al. 2000). SHEDS utilizes the Xue et al. (2004) approach for longitudinal diary assembly.

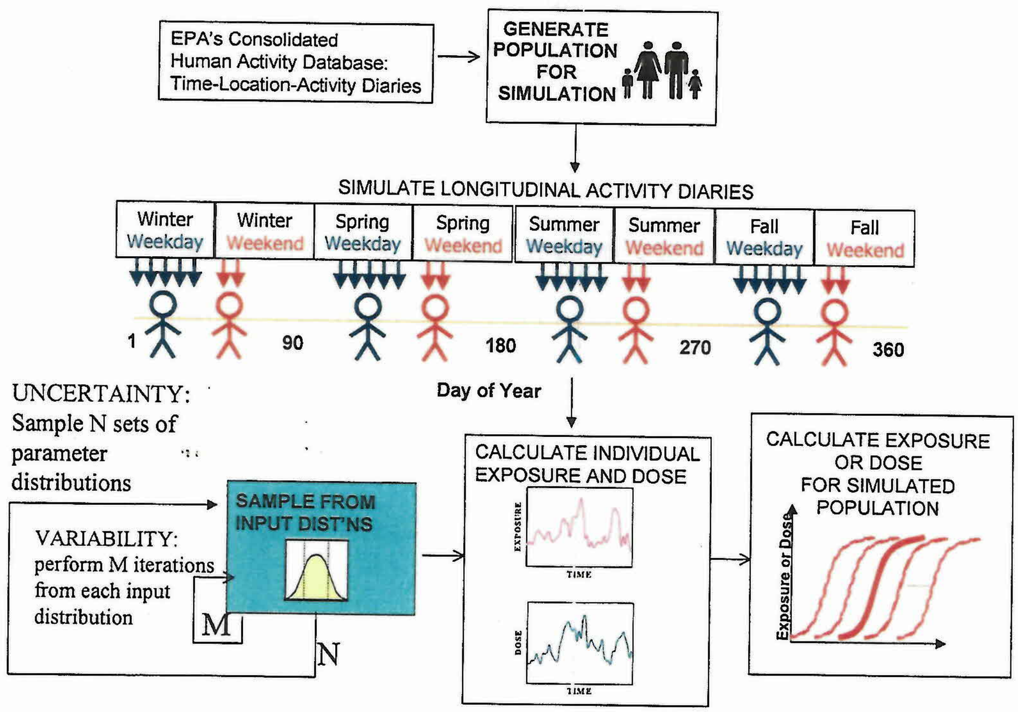



Figure 3. Overview of SHEDS residential methodology.

For each individual in a SHEDS-Residential run, the following general steps are applied (see the SHEDS Technical Manual for more detail: Glen et al., 2010):

1. Randomly select the age, gender, and other demographic properties of interest, given the distribution of the target population.
2. Generate a longitudinal activity diary, which indicates the sequence and duration of activities and locations for that person. For the residential module, these are based on sequential time-location-activity diaries from EPA's CHAD database.
3. Generate concentration time series for each potential contact medium (e.g., indoor air, indoor smooth surfaces, indoor textured surfaces, outdoor lawn).
4. Simulate the contacts between the individual and the affected media. These depend on the diary activity/location information and contact probabilities derived from user-specified inputs.
5. Calculate pathway-specific exposure time series for the individual, using the results of the prior two steps and user-specified distributions for exposure factors.
6. Generate an approximation for the components of the intake or absorbed dose time series and export these for use in a simple PK or more complex PBPK model.
7. Time-aggregate to daily totals of absorbed dose.

The SHEDS-Residential model was applied to the dose modeling estimation for NYC school PCB data because the school environment is, in many ways, similar to the residential environment, particularly with regard to multiple exposure pathways. Rather than using residential activity data, school activity data from CHAD were used in this PCBs assessment.

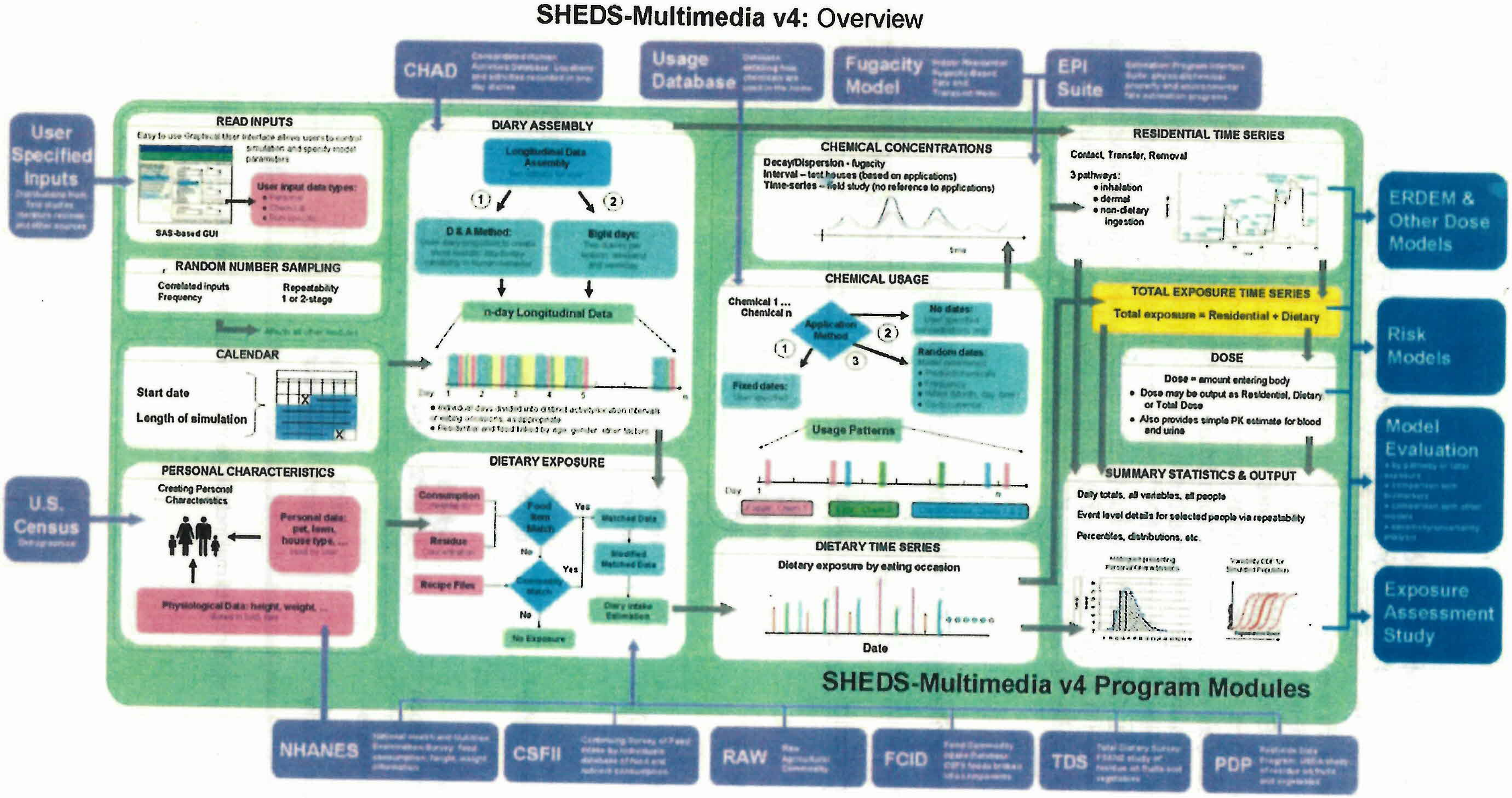



Figure 4. General overview of SHEDS-Residential exposure model.

## Input Data for SHEDS School PCB Modeling

Key inputs for PCBs exposure simulation are concentrations of PCBs in various media. Measurement data from the three schools in New York City were pooled and fitted to lognormal distributions for indoor air, soil and wipe sample concentrations for total PCBs (Table 8). Only those soil results for samples collected from the 0 – 2" depth were used as inputs to the model. Soil concentration was used as a surrogate for indoor dust total PCBs concentration since there was no measurement for this medium for those three schools. Also, outdoor air concentrations from other studies (see Appendix A) were used for PCB exposure simulation because there were insufficient measurements to fit distributions and the detection limit for the NYC measurements was high relative to typical outdoor air levels. Outdoor air measurement results used in this analysis had a mean of 18 ± 25, median 0.4, and a range of 0.18 to 60 ng/m$^3$ total PCBs. Outdoor air concentrations were applied to the fraction of time spent outdoors at school.

Table 8. Key input concentration variables for the SHEDS-Multimedia model PCB Assessment.

| Input Concentration or Process | Units | Distributional Form | Distributional Parameters [a] $v_1$ | $v_2$ | $v_3$ |
|---|---|---|---|---|---|
| Soil PCB concentration | ug/kg | lognormal | 586 | 3.88 | |
| Dust PCB concentration | ug/kg | lognormal | 586 | 3.88 | |
| outdoor air PCB concentration | ug/m^3 | lognormal | 0.002082 | 12.93803 | |
| **Pre-remediation** | | | | | |
| Indoor air PCB concentration | ug/m^3 | lognormal | 0.279 | 4.6 | |
| Surface residue PCB concentration | ug/cm^2 | lognormal | 0.00129 | 2.31 | |
| **Post-remediation** | | | | | |
| Indoor air PCB concentration | ug/m^3 | lognormal | 0.272 | 2.79 | |
| Surface residue PCB concentration | ug/cm^2 | lognormal | 0.001026 | 2.384 | |
| **Added ventilation** | | | | | |
| Indoor air PCB concentration | ug/m^3 | lognormal | 0.1561 | 2.57 | |
| Surface residue PCB concentration | ug/cm^2 | lognormal | 0.001026 | 2.384 | |
| **Added removal of light fixture** | | | | | |
| Indoor air PCB concentration | ug/m^3 | lognormal | 0.0747 | 2.88 | |
| Surface residue PCB concentration | ug/cm^2 | lognormal | 0.001026 | 2.384 | |

[a] Distributional parameters ($v_1$, $v_2$, $v_3$) for lognormal include geometric mean and geometric standard deviation.
* half DL for not detected

Absorption parameters of PCBs by humans are another set of important inputs (Table 9, information from ATSDR, 2000). Absorption information and their application in SHEDS is described below.

Inhalation Absorption
PCBs, when administered orally, are well absorbed by experimental animals and at generally high fractions by humans (ATSDR, 2000). Available inhalation absorption data are insufficient for estimating lung absorption rates (ATSDR, 2000); thus, a value of 70% was used for this PCBs exposure simulation, and sensitivity analyses were conducted using 35% and 100% to examine the impact on modeled dose estimates.

Gastrointestinal Absorption
As with fats and other fat-soluble chemicals, PCBs are most likely absorbed from the gut via lymphatic circulation and consequently avoid first-pass metabolism in the liver (Hansen 1999).

Price et al. (1972) found that 88% of the ingested PCBs were not excreted, and were therefore assumed to be retained in the body (7–9 year old girls). This estimate of PCB absorption in young girls is supported by the more comprehensive, congener specific mass balance study of Schlummer et al. (1998).

Retention was estimated to be >90% and 85.4% of the administered dose in monkeys (Allen et al. 1974b) and ferrets (Bleavins et al. 1984), respectively. An absorption value of 85% was used for the simulation.

Dermal Absorption
Experimental data on the percutaneous absorption of PCBs in humans is limited to in vitro studies that used human cadaver skin (Wester et al. 1990, 1993) with 14C-labeled Aroclor 1242 and 1254. Over a 24-hour period, 2.6, 10, and 43% of the dose was retained in human skin when the Aroclor 1242 was formulated in soil, mineral oil, or water, respectively. Similar results were observed with Aroclor 1254, with 1.6, 6.4, and 44.3% of the dose retained in human skin, following PCB exposure in a soil, mineral oil, or water vehicle, respectively. The in vitro data indicate that PCBs readily enter human skin and are available for systemic absorption, and that the dosing vehicle has a major role in regulating the relative retention of PCBs in human skin.

In a related study, Wester et al. (1990, 1993) assessed the in vivo percutaneous absorption of PCBs in adult female Rhesus monkeys. Topical administration of Aroclor 1242 resulted in 14, 20, 18, and 21% absorption of the administered dose when formulated in soil, mineral oil, trichlorobenzene, or acetone, respectively. In contrast to the above in vitro results with human skin, the vehicle had little effect on the systemic absorption of the PCBs applied to the skin of monkeys. This may be due to the uncertain viability of the human skin used in the in vitro studies and the fact that the in vitro study primarily assessed retention of PCBs in human skin and could not estimate systemic absorption.

Absorption efficiency ranged from 0.15 to 34% of the applied radioactivity in the monkeys and averaged 33% (42% chlorine) and 56% (54% chlorine) of the applied radioactivity in the guinea pigs.

For this simulation, 2% was used for dermal absorption rate per day for dust or soil and uniform distribution with 10% and 40% for the daily dermal absorption rate for the residues.

Other default inputs are listed in Tables 9 and 10 (from Appendix G default values for non-chemical specific variables from the SHEDS-Multimedia version 4 Technical Manual; Glen, 2010). The U.S. EPA Child-specific Exposure Factors Handbook was consulted in selecting input values, but relevant data for fitting distributions for soil and dust contact and ingestion were available from Kissel et al. (1996), Holmes et al. (1999), and Ozkaynak et al. (2010) and were used in this analysis. The object mouthing rates shown in Table 10 were used in conjunction with the residue data from the dermal wipe samples.

Table 9. Key input exposure and dose factor variables for the SHEDS-Multimedia model PCB assessment.

| Input Concentration or Process | Units | Distributional Form | Distributional Parameters [a] $v_1$ | $v_2$ | $v_3$ |
|---|---|---|---|---|---|
| absorption fraction for lungs | [-] | point | 0.7 | | |
| dermal absorption rate per day for dust or soil | 1/day | point | 0.02 | | |
| dermal absorption rate per day for surface residues | 1/day | uniform | 0.1 | 0.43 | |
| GI tract absorption rate per day for dust or soil | 1/day | point | 0.85 | | |
| GI tract absorption rate per day for surface residues | 1/day | point | 0.85 | | |
| bioavailability fraction for dust/soil | [-] | point | 1 | | |
| bioavailability fraction for surface residues | [-] | point | 1 | | |
| residue-skin transfer efficiency | [-] | normal | 0.051 | 0.022 | |
| soil-skin adherence factor | mg/cm2 | lognormal | 0.11 | 2 | |
| body-surface fractional contact rate | 1/20min | beta | 42 | 166 | |
| hand-surface fractional contact rate | 1/20min | Weibull | 10 | 2.5 | |
| fraction of body unclothed | [-] | beta | 3 | 6.7 | |
| surface-skin transfer coefficient for body (unclothed) | cm2/hr | lognormal | 3070 | 1.68 | |
| surface-skin transfer coefficient for hand | cm2/hr | lognormal | 3070 | 1.68 | |
| dust ingestion rate (indoor, direct only, 6<=age <=10) | mg/hour | lognormal | 0.939 | 3.82 | |
| dust ingestion rate (indoor, direct only, age >=11) | mg/hour | point | 0 | | |
| soil ingestion rate (outdoor, direct only, 6<=age <=10) | mg/hour | lognormal | 0.528 | 6.73 | |
| soil ingestion rate (outdoor, direct only, age >=11) | mg/hour | point | 0 | | |

[a] Distributional parameters ($v_1$, $v_2$, $v_3$): lognormal (geometric mean, geometric standard deviation); normal (mean, standard deviation); uniform (minimum, maximum) ; triangle (minimum, mode, maximum).

Table 10. Key input variables for the SHEDS-Multimedia model.

| Input Concentration or Process | Units | Distributional Form | Distributional Parameters [a] $v_1$ | $v_2$ | $v_3$ |
|---|---|---|---|---|---|
| hand mouthing events per hour (indoor, 6<=age <=10) | events/hr | Weibull | 1.36 | 7.34 | |
| hand mouthing events per hour (outdoor, 6<=age <=10) | events/hr | Weibull | 0.49 | 1.47 | |
| hand mouthing events per hour (age >=10) | events/hr | point | 0 | | |
| fraction of surface of one hand that enters mouth | [-] | beta | 3.7 | 25 | |
| object mouthing events per hour (indoor, 6<=age <=10) | events/hr | Weibull | 0.84 | 1.2 | |
| object mouthing events per hour (outdoor, 6<=age <=10) | events/hr | Weibull | 0.55 | 1.1 | |
| object mouthing events per hour (age >=11) | events/hr | point | 0 | | |
| object-surface concentration ratio | [-] | uniform | 0 | 0.2 | |
| object-mouth contact area | cm2 | exponential | 1 | 10 | |
| object-mouth transfer efficiency | [-] | beta | 2 | 8 | |
| transfer coefficient for object mouthing (age >=6) | cm2/hr | point | 0 | | |
| removal efficiency during bath/shower | [-] | uniform | 0.9 | 1 | |
| removal efficiency during events without water | 1/hr | point | 0 | | |
| removal efficiency during mouthing | [-] | beta | 2 | 8 | |
| removal efficiency during hand washing | [-] | uniform | 0.3 | 0.9 | |
| mean # hand washes/day per person | 1/day | lognormal | 3.74 | 2.63 | |
| maximum dermal loading for body | ug/cm2 | triangle | 0.1 | 0.6 | 2.1 |
| maximum dermal loading for hands | ug/cm2 | triangle | 0.1 | 1 | 2.1 |

[a] Distributional parameters ($v_1$, $v_2$, $v_3$): lognormal (geometric mean, geometric standard deviation); normal (mean, standard deviation); uniform (minimum, maximum) ; triangle (minimum, mode, maximum).

Inhalation rate

The basal metabolic rate (bmr) is calculated from a regression equation using body weight as the independent variable. The units for bmr are megajoules per day. The slope, intercept, and standard deviation of the residual are taken from the body weight and surface area files by age and gender. A minimum value of 0.1 megajoules per day is permitted. The basal inhalation rate is the rate in effect for activities with a METS of one and has units of cubic meters of air per hour. The basal alveolar ventilation rate, bva, is related to the basal metabolic rate

$$bva = bmr * 0.166 * 0.01963 * (0.20 + 0.01 * u) * 60$$

The factor 0.166 converts from megajoules per day to kilocalories per minute. The factor 0.01963 converts from liters of oxygen consumed to cubic meters of air inhaled. The variable “u” is uniformly distributed between zero and one, and then term (0.20 + 0.01* u) represents the metabolic efficiency (liters of oxygen consumed per kilocalorie expended). The final factor of 60 converts per minute rate to per hour rate. Multiplication of metabolic ratio of energy expenditure for an activity to the resting rate (Mets) and bva leads to inhalation rate for SHEDS. In this way, we link age, body weight and activity levels with inhalation rate. SHEDS is using macro activity, therefore, we only use short-term inhalation rates. Table 11 displays summary statistics of average inhalation rates by age groups.

Table 11. Average inhalation rate ($m^3$/day)

| age group (yr) | mean | std | p5 | p25 | p50 | p75 | p95 | p99 |
|---|---|---|---|---|---|---|---|---|
| 06-10 | 8.20 | 1.85 | 5.82 | 6.96 | 7.91 | 9.01 | 11.95 | 14.46 |
| 11-13 | 10.98 | 2.50 | 7.56 | 9.16 | 10.68 | 12.34 | 15.72 | 18.21 |
| 14-18 | 12.86 | 3.01 | 8.60 | 10.78 | 12.50 | 14.60 | 18.24 | 21.06 |

Time activity in school

The simulated population of 6-18 year-old children was generated using ~35,000 person-days from the new CHAD database; time-location-activity diaries were selected according to age and school attendance information. Longitudinal activity diaries of the simulated schoolchildren were generated using a published method to optimize inter- and intra- individual variability (that uses 8 CHAD person-days by season and weekday/weekend for each age/gender cohort; Xue et al., 2004). Applying this method generated an average 6.34 hours indoor and 0.2 hours outdoor during school time. Higher ventilation rates were applied for the outdoor time due to the higher levels of physical activity. The longitudinal activity patterns for each individual were combined with available PCB concentration data and exposure factors and inserted into exposure pathway equations as described in the SHEDS-Multimedia technical manual.

Only PCB exposures incurred during school hours (in/around the school) were modeled; neither dietary intake nor intake away from school was considered . Routes considered were inhalation, dermal contact, and soil ingestion. For dermal contact, wipe data were used; these likely include both PCB residues and PCBs bound to dust. We assumed children 11 years and older had no soil/dust ingestion due to lack of data, however, this likely results in a small underestimation in the total exposure for children 11-18 years old. Direct dermal contact with and ingestion of caulk was also not included due to an absence of information on relevant contact rates and how much PCBs would be available for dermal transfer from caulk-bound PCBs.

Detection rate

Detection limits (DL) for air were usually about 50 ng/$m^3$. The DL for soil was 0.5 mg/kg for most samples and 0.1 ug/100 $cm^2$ for all wipe samples. A value of one-half of the DL was substituted for samples with values <DL.

The models were re-run using a substitution of zero for values <DL; overall model results were similar with those using one-half DL substitution. Only the model results using substitution of one-half of the DL are reported here.

## SHEDS MODEL RESULTS

### Distributions of Estimated Doses

The SHEDS model was used to generate estimated PCB dose distributions resulting from exposures to environmental levels measured at the three NYC schools. The model was run for three age groups (6-10, 11-14, and 14-18 years old) at the pre-remediation, post-caulk remediation, post-ventilation/cleaning, and post-light fixture removal time points. Mean estimates of absorbed dose, and the estimated absorbed doses across selected percentile of the modeled distribution are shown in Tables 12 – 14. For the 6-10 year-old age group the estimated absorbed dose was 0.022 µg/kg/day at the 50$^{th}$ percentile of the distribution and 0.30 µg/kg/day at the 95$^{th}$ percentile. Estimates of absorbed PCB doses decreased at each of the three post-remediation time points. Following light fixture removal, the estimated absorbed dose for 6-10 year-olds decreased to 0.007 µg/kg/day at the 50$^{th}$ percentile and 0.010 µg/kg/day at the 95$^{th}$ percentile. Graphic visualization of the distributions of estimated PCB doses, and the differences between time points, is provided for the 6-10 year-olds in Figure 5.

Estimated PCB doses decreased with increasing age, with 11-13 year-olds having lower doses than the 6-10 year-olds and the 14-18 year-olds having lower estimated doses than the 11-13 year-olds. The primary reasons for the decrease in estimated dose (µg/kg/day) with age was the increasing body weight with age and the much lower soil/dust ingestion rate for children 11-18 years old.

A distribution of estimated PCB doses resulting from exposures in school environments was also generated using extant PCB measurement data not associated with the 2010 measurements at the three NYC schools. These data were gleaned from several reports and internet sources and included measurements for indoor air, dust, surface wipes, and soil (see Appendix A). The estimated doses using other extant data are shown in Tables 12 – 14 for comparison. In general, the estimated doses using data from the three NYC schools are similar to estimates using other data.

The percentage decrease in estimated doses for each of the three remediation measurement time points, and the cumulative decrease in estimated dose from the pre-remediation time point are reported in Table 15. Overall, there was an approximately 65 – 70% cumulative decrease in estimated doses from the pre-remediation to the post-light fixture removal time points. These decreases in estimated doses track the decreases in indoor air concentration across the time points. For these three schools, the largest reductions appeared to be at the cleaning/ventilation and the light-fixture removal time points. It is important to recognize that the relative magnitude of the changes in estimated doses are specific to the conditions at the three NYC pilot schools. Remedial actions might have different impacts for schools with other conditions and PCB sources.

Table 12. Total Absorption of PCBs Estimated by SHEDS with Measurement Data from Three NYC Schools (6 - 10 year olds; units: µg/kg/day)[a]

| School Condition | Mean | Std. Dev. | Percentiles of the Distribution of Dose Estimates | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | p5 | p25 | p50 | p75 | p95 | p99 |
| Pre-remediation | 0.022 | 0.004 | 0.016 | 0.020 | 0.022 | 0.025 | 0.030 | 0.032 |
| Post-caulk remediation | 0.019 | 0.004 | 0.013 | 0.016 | 0.019 | 0.021 | 0.025 | 0.030 |
| Post-ventilation or cleaning | 0.012 | 0.002 | 0.008 | 0.010 | 0.012 | 0.013 | 0.016 | 0.017 |
| Post-light fixture removal | 0.007 | 0.002 | 0.005 | 0.006 | 0.007 | 0.008 | 0.010 | 0.011 |
| Estimates using other data[b] | 0.021 | 0.009 | 0.012 | 0.016 | 0.019 | 0.024 | 0.037 | 0.054 |

[a] One-half the detection limit substituted for measurement results below the DL.
[b] Using school measurement data not associated with the 2010 measurements at the three NYC schools (see Appendix A).

Table 13. Total Absorption of PCBs Estimated by SHEDS with Measurement Data from Three NYC Schools (11 - 13 year olds; units: µg/kg/day) [a]

| | | | Percentiles of the Distribution of Dose Estimates | | | | | |
|---|---|---|---|---|---|---|---|---|
| School Condition | Mean | Std. Dev. | p5 | p25 | p50 | p75 | p95 | p99 |
| Pre-remediation | 0.018 | 0.004 | 0.011 | 0.015 | 0.017 | 0.020 | 0.024 | 0.030 |
| Post-caulk remediation | 0.015 | 0.004 | 0.010 | 0.013 | 0.015 | 0.018 | 0.022 | 0.027 |
| Post-ventilation or cleaning | 0.009 | 0.002 | 0.006 | 0.008 | 0.009 | 0.011 | 0.014 | 0.015 |
| Post-light fixture removal | 0.006 | 0.001 | 0.004 | 0.005 | 0.005 | 0.006 | 0.008 | 0.010 |
| Estimates using other data[b] | 0.016 | 0.006 | 0.009 | 0.012 | 0.015 | 0.019 | 0.027 | 0.034 |

[a] One-half the detection limit substituted for measurement results below the DL.
[b] Using school measurement data not associated with the 2010 measurements at the three NYC schools (see Appendix A).

Table 14 . Total Absorption of PCBs Estimated by SHEDS with Measurement Data from Three NYC Schools (14 - 18 year olds; units: µg/kg/day) [a]

| | | | Percentiles of the Distribution of Dose Estimates | | | | | |
|---|---|---|---|---|---|---|---|---|
| School Condition | Mean | Std. Dev. | p5 | p25 | p50 | p75 | p95 | p99 |
| Pre-remediation | 0.012 | 0.005 | 0.004 | 0.009 | 0.012 | 0.016 | 0.020 | 0.025 |
| Post-caulk remediation | 0.011 | 0.004 | 0.004 | 0.008 | 0.010 | 0.013 | 0.018 | 0.021 |
| Post-ventilation or cleaning | 0.007 | 0.002 | 0.003 | 0.005 | 0.007 | 0.008 | 0.011 | 0.012 |
| Post-light fixture removal | 0.004 | 0.002 | 0.001 | 0.003 | 0.004 | 0.005 | 0.007 | 0.008 |
| Estimates using other data[b] | 0.011 | 0.005 | 0.004 | 0.008 | 0.011 | 0.014 | 0.020 | 0.028 |

[a] One-half the detection limit substituted for measurement results below the DL.
[b] Using school measurement data not associated with the 2010 measurements at the three NYC schools (see Appendix A).

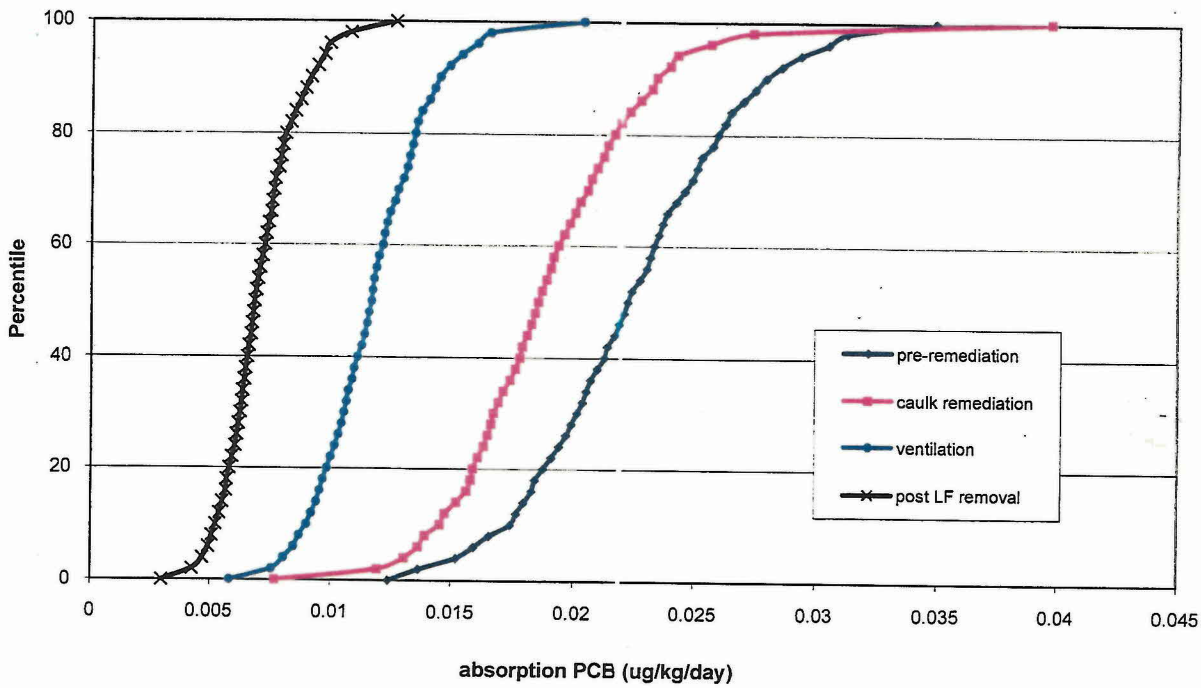



Figure 5. SHEDS distributions of estimated total PCB absorption for 6–10 year-olds using measurements from three NYC schools under different conditions.

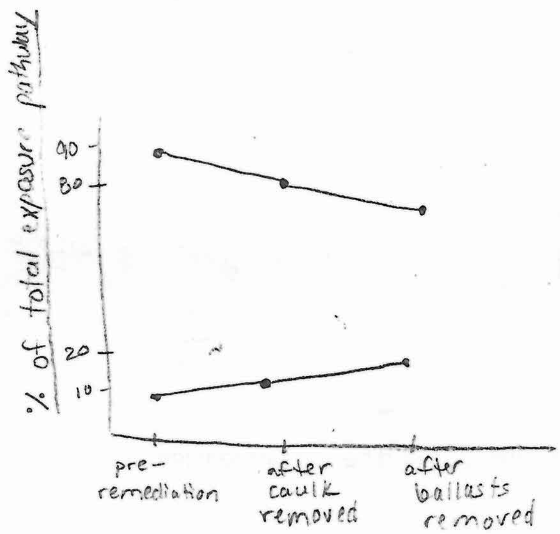
Table 15. Percent Decrease in Total Estimated PCB Dose for Different Levels of Remedial Action at the Mean and Selected Percentiles of Dose

| | % Decrease For Each Remediation Step[a] | | | | Cumulative % Decrease from Pre-Remediation[b] | | | |
|---|---|---|---|---|---|---|---|---|
| School Condition | Mean | p50 | p75 | p95 | Mean | p50 | p75 | p95 |
| 6 – 10 Year Olds | | | | | | | | |
| Post-caulk remediation | -14 | -14 | -16 | -17 | -14 | -14 | -16 | -17 |
| Post-ventilation or cleaning | -37 | -37 | -38 | -36 | -45 | -45 | -48 | -47 |
| Post-light fixture removal | -42 | -42 | -38 | -38 | -68 | -68 | -68 | -67 |
| 11 – 13 Year Olds | | | | | | | | |
| Post-caulk remediation | -17 | -12 | -10 | -8 | -17 | -12 | -10 | -8 |
| Post-ventilation or cleaning | -40 | -40 | -39 | -36 | -50 | -47 | -45 | -42 |
| Post-light fixture removal | -33 | -44 | -45 | -43 | -67 | -71 | -70 | -67 |
| 14 – 18 Year Olds | | | | | | | | |
| Post-caulk remediation | -8 | -17 | -19 | -10 | -8 | -17 | -19 | -10 |
| Post-ventilation or cleaning | -36 | -30 | -38 | -39 | -42 | -42 | -50 | -45 |
| Post-light fixture removal | -67 | -43 | -38 | -36 | -67 | -67 | -69 | -65 |

[a] The percentage decrease in estimated dose from the immediately preceding measurement time point.
[b] The cumulative percentage decrease from the estimated dose at the pre-remediation time point.

**Estimates of Contributions from Different Exposure Pathways**

Information on the relative importance and contribution of different exposure pathways to the total exposure can help inform mitigation decision-making. The SHEDS model provides estimates of the exposure from each relevant pathway. Figures 6 – 7 show the apportionment of inhalation, dermal absorption, and non-dietary ingestion pathways for the estimated PCB doses at different percentiles of the distributions for the 6-10 year-old age group. Overall, the inhalation pathway would appear to be the predominant route of exposure based on data from the NYC schools. Non-dietary and dermal exposures would account for less than 10% of the total dose for 6-10 year-olds at the pre-remediation time point (when PCB concentration is air were greatest). As the air concentrations decreased at succeeding post-remediation time points, the relative contribution of dermal and non-dietary ingestion sources increased (assuming residue, soil, and dust levels remained the same) but inhalation would still account for most of the total dose for 6-10 year olds at the post-light fixture removal time point. Similar patterns were seen for the older age groups. The contribution of non-dietary ingestion was not modeled for the two older age groups due to the lack of hand-to-mouth data, but might be expected to be lower than for 6-10 year olds because of reduced hand-to-mouth activity.




This is just dealing with the percentage of how the PCBs get in the body, not the actual levels of PCBs.

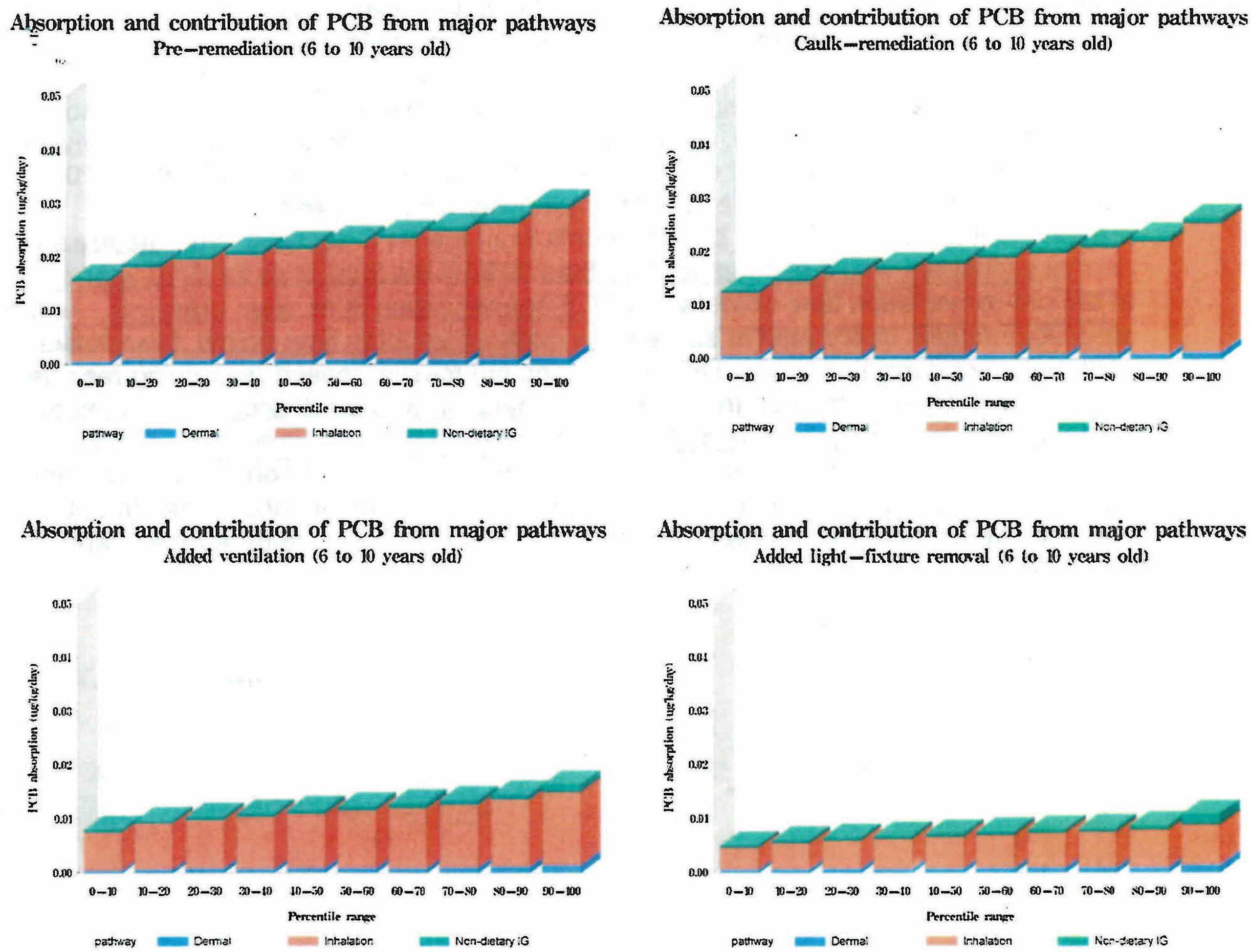



Figure 6. Estimation of PCB dose from different pathways at different percentiles for 6-10 year-olds.

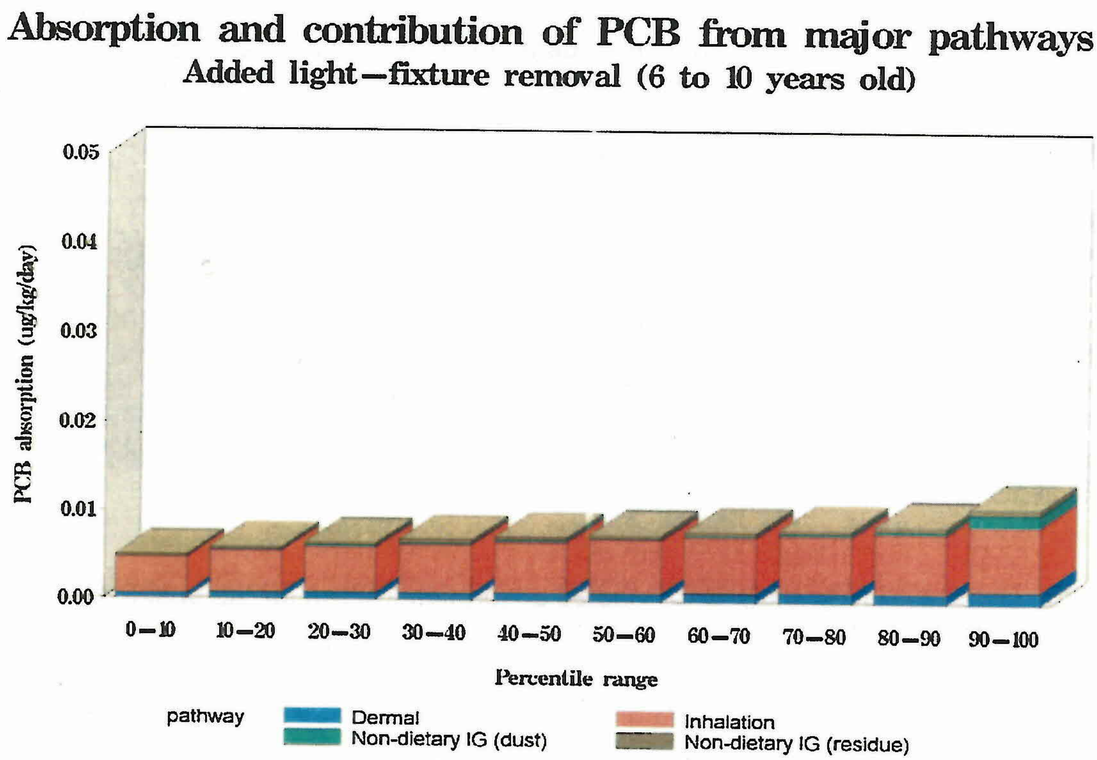



Figure 7. Estimation of PCB dose from different pathways at different percentiles (with dust and residue contributions to non-dietary ingestion shown separately).

## SHEDS MODEL SENSITIVITY ANALYSIS

Model sensitivity analyses are used to assess the relative impact and importance of uncertainties in model parameters and input data. Limited sensitivity analysis was conducted for two important but uncertain parameters used in the SHEDS PCB model. These include the fraction of PCBs absorbed in the lungs following inhalation, and the concentration of PCBs in dust in the schools.

### Lung PCB Absorption Sensitivity

To the best of our knowledge, the absorption fraction for PCBs through the lungs following inhalation has not been determined. A value of 70% was assumed for the SHEDS PCB analysis. In the first sensitivity test, the impact of using 35% or 100% absorption was examined for 6-10 year-olds at the post-light fixture removal time point. Table 16 shows that using a lung absorption fraction of 35% resulted in a 40% decrease in the estimated dose at the 50$^{th}$ percentile and a 37% decrease at the 95$^{th}$ percentile. Using a lung absorption fraction of 100% resulted in an increase in the estimated dose of 40% at the 50$^{th}$ percentile and a 33% increase at the 95$^{th}$ percentile.

Table 16. Dose sensitivity analysis for inhaled absorption fraction for the post-light fixture removal time point (6–10 year-olds).

| | Estimated total PCB Absorption (µg/kg/day) | | | | |
|---|---|---|---|---|---|
| Condition | Mean | Std. Dev. | p50 | p75 | p95 |
| Base model[a] | 0.0070 | 0.0015 | 0.0068 | 0.0079 | 0.0098 |
| Lung absorption fraction 35% | 0.0043 | 0.0013 | 0.0041 | 0.0048 | 0.0062 |
| Lung absorption fraction 100% | 0.0095 | 0.0020 | 0.0095 | 0.011 | 0.013 |
| | % Change from Base Model | | | | |
| Lung absorption fraction 35% | - 39 | -- | - 40 | - 39 | - 37 |
| Lung absorption fraction 100% | + 36 | -- | + 40 | + 39 | + 33 |

[a] Base model: 70% absorption fraction for inhalation exposure via the lungs.

**Indoor Dust PCB Concentration Sensitivity**
Indoor dust samples were not collected from the three NYC schools. Dust can be an important source of exposure for children. In the SHEDS model analyses the distribution of PCBs in soil was used as a surrogate for PCBs in dust. However, if dust PCB concentrations are greater than the soil levels, then the dose estimates could be underestimated and the relative contribution of dust to the total dose could be higher than reported. In residential studies indoor dust levels are often found to be higher than those for soil. Without dust measurement data, it is not possible to directly assess if this could also be true for the 2010 NYC pilot schools.

Due to the uncertainty in dust PCB concentrations, sensitivity analyses were conducted to assess the impact of higher dust PCB concentrations on estimates of absorbed doses. Because the ratio of geometric mean dust to soil PCB concentrations for data from schools other than the three NYC pilot schools was 4.5 (see Appendix A), a five-fold increase in dust concentrations was used in the sensitivity analysis. The five-fold increase was applied to both the pre-remediation and the post-light fixture removal time points.

As shown in Table 17, a five-fold increase in dust PCB concentrations at the pre-remediation time point would result in a 3% increase in the estimated dose at the 50$^{th}$ percentile, and an 11% increase at the 95$^{th}$ percentile. A five-fold increase in dust PCB concentrations at the post-light fixture removal time point would result in a 16% increase in the estimated dose at the 50$^{th}$ percentile, and an 28% increase at the 95$^{th}$ percentile. The impact of a five-fold increase in dust PCB concentrations is more pronounced at the post-light fixture removal time point because the indoor air concentrations at that time point are much lower than those at the pre-remediation time point.

Sensitivity analyses have been performed for two SHEDS model parameters. Future research could involve additional sensitivity analyses that could help identify and prioritize data gaps and guide future data collection efforts. For example, collection and analysis of dust samples would reduce the uncertainty in modeled dose estimates.

Table 17. Dose sensitivity analysis for a 5-fold increase in dust PCB concentrations at the pre-remediation and post-light fixture removal time points (6–10 year-olds).

| | Estimated total PCB absorption (μg/kg/day) | | | | |
|---|---|---|---|---|---|
| Condition | Mean | Std. Dev. | p50 | p75 | p95 |
| Pre-Remediation | | | | | |
| Base model[a] | 0.0224 | 0.0042 | 0.0222 | 0.0252 | 0.0300 |
| Dust 5-fold increase | 0.0234 | 0.0051 | 0.0228 | 0.0260 | 0.0333 |
| Post-Light Fixture Removal | | | | | |
| Base model[a] | 0.0070 | 0.0015 | 0.0068 | 0.0079 | 0.0098 |
| Dust 5-fold increase | 0.0084 | 0.0028 | 0.0079 | 0.0093 | 0.0125 |
| | | | % Change from Base Model | | |
| Pre-Remediation | | | | | |
| Dust 5-fold increase | + 4 | -- | + 3 | + 3 | + 11 |
| Post-Light Fixture Removal | | | | | |
| Dust 5-fold increase | + 20 | -- | + 16 | + 18 | + 28 |

[a] Base model: Indoor dust geometric mean 586 ug/kg (geometric standard deviation 3.87).

## LIMITATIONS

Models can be useful tools for estimating human exposure to chemicals in the environment, but it is important to understand the limitations and uncertainties associated with model inputs and outputs. Exposure models are designed to use information about levels of chemical in an environment, and a person's contact with chemicals in that environment, to estimate the amount of exposure that may occur. Simple point-estimation models often do not incorporate variability in environmental levels and human contact with the environment and do not characterize the range of exposures likely to be encountered by a human population or sub-population. The SHEDS model incorporates variability in chemical concentrations and some aspects of human activity (e.g., time spent in different locations and activities) in order to estimate distributions of exposure and dose. However, there are uncertainties in some of the assumptions and exposure pathways/scenarios modeled (e.g., ingestion of caulk was not modeled, and outdoor soil was used as a surrogate for indoor dust), information inputs used in the model and in some of the underlying model parameters. Also, while SHEDS includes sophisticated exposure algorithms, the dose estimation module in SHEDS is a simple 1-compartment PK model based on daily absorption rates, and is intended for screening purposes; it can be linked to PBPK models for more sophisticated dose modeling if sufficient data are available (but they are not available at this time for PCBs; thus, the SHEDS PK model was used in this study).

While there are uncertainties in the SHEDS dose estimates, the probabilistic modeling approach provides estimates for the range of doses based on variability in concentrations and activity. Such information can inform risk assessments by characterizing not only the average dose, but also the upper end of exposures and doses in a population. It is also important to recognize that many of the uncertainties in parameters for the SHEDS model would also apply to other dose estimation approaches, including point-estimation models.

Some of the limitations and uncertainties important for modeling PCB exposures in school environments are described below. In many of these areas, uncertainties can be reduced in the future through collection of additional data or information.

<u>Levels of PCBs in school dust</u> – Interior dust samples were not collected as part of the NYC pilot study. Dust can be an important source of exposure through inhalation, non-dietary ingestion, and dermal contact. While the air measurements presumably include airborne dust, neither dust loading nor PCB concentration in dust data are available. For the purposes of this modeling effort, the distribution of PCB concentrations in soil was used as a surrogate for indoor dust. Wipe sample data were not used as the surrogate for dust because the wipes likely contained some distribution of dust-bound and surface-residue PCBs, but that distribution cannot be defined from the measurement. Also, the μg/cm$^2$ units for wipes cannot be simply translated to the μg/kg units for dust. Because contaminant concentrations in dust are often higher than those in soil (at least in residential environments), a sensitivity analysis was performed to assess the impact of five-fold higher dust concentrations on estimated PCB doses.

Sensitivity tests showed that assuming a five-fold higher dust concentration for these three schools would result in median dose estimates for 6 – 10 year-olds only 3% higher at the pre-remediation time point, and 16% higher at the post-light fixture removal time point. The uncertainty in concentrations of PCBs in dust can be reduced by collection of dust samples; protocols for future sampling should including bulk dust sample collection.

Building ventilation conditions – Air samples were collected at multiple locations (including classrooms, gymnasiums, cafeterias, transitional spaces) at several time points in three schools under different conditions. Air concentrations of indoor pollutants are strongly impacted by ventilation rates in a building or in a room. Actual rates of ventilation with outdoor air and between adjoining spaces are difficult to measure in individual rooms in older buildings. While the air PCB measurements certainly incorporated some level of variability in ventilation effects, it is not possible to quantitatively characterize the impact of ventilation on air concentrations from the data available when this report was prepared. Exposures (and doses) might be substantially different under different ventilation conditions. Doubling the outdoor air ventilation rate to a room would result in a 50% decrease in indoor air PCB concentrations, while reducing the outdoor air ventilation rate by half would double indoor air PCB levels, all other factors being equal. Uncertainties due to ventilation effects can be reduced by collection of baseline data on ventilation and, where successive measurements are performed, making those measurements under similar ventilation conditions. However, it will remain difficult to accurately assess air flows between a room and other adjacent spaces in older buildings, limiting the ability to fully account for ventilation impacts on PCBs in indoor air.

Dermal contact and non-dietary ingestion rates – Dermal contact rates with potentially contaminated surfaces have not been directly assessed for children in school environments. Likewise, non-dietary ingestion rates of PCBs have not been directly characterized for children in school environments. Thus, values from the literature based on other studies were used as model inputs. These values are the best available information at this time.

Lung absorption of PCBs – Very little information is available to determine the inhalation absorption of PCBs through the lungs; thus, a value of 70% absorption was assumed for this purpose and sensitivity tests were performed using values of 35% and 100% absorption to examine the impact on estimates of dose. Because a majority of the modeled dose resulted from the inhalation pathway, the value selected for lung absorption can have an important impact on dose estimates. Sensitivity analyses indicated that the median dose estimate for 6 – 10 year-old children would be 40% lower assuming a lung absorption of 35%, and 40% higher assuming a lung absorption of 100%.

Dermal absorption of PCBs – Some animal and human cadaver skin absorption data are available for selected Aroclors. However, dermal absorption may be affected by a number of factors including skin conditions; dermal loading rates; and how much of the

PCBs are bound to soil, dust, or caulk particles. There remains uncertainty in absorption rates in natural environments under different conditions. The default values from the literature are the best available information for estimating dermal absorption at this time.

Dietary and residential exposure to PCBs – SHEDS modeling estimates in this report are limited to estimates of absorbed doses (and exposure pathway analysis) resulting from school environments. A more complete model assessment would include the contribution from dietary sources as well as contributions from residential exposures. The evaluation of dietary exposures is important because dietary intake is often characterized the primary route of exposure to PCBs in the general population. The most recent published estimates of total PCB dietary intake are based on FDA Total Dietary Study 1997 data, and include a mean dietary intake of 0.003 µg/kg/day for 6 and 10-year old children (ATSDR 2000). This value can be compared to the median estimates of 0.022 µg/kg/day (pre-remediation) and 0.007 µg/kg/day (post-light fixture removal) time points for 6 – 10 year-old children for exposures from the school environment (Table 12). It is possible that PCB levels in foods have continued to decrease since 1997; in fact the Total Diet Study data from 2003 showed detection of PCBs in only two analyses of salmon. Given the small amount of measurable data in the most recent Total Diet Study, it is not clear whether there are sufficient U.S. data to support development of distributional parameters for SHEDS modeling. Additional time and effort are needed to examine the extant PCB dietary data (including Total Diet Study data from the FDA) as well as residential data to determine their suitability for incorporation into the SHEDS model. NERL researchers will continue to collect and assess extant data in these areas and perform additional SHEDS modeling, if feasible.

The factors discussed above, as well as other model inputs, contribute to uncertainty in modeled exposure and dose estimates resulting from PCBs in school environments. Sensitivity testing for two important parameters helps define some of the range of uncertainty. Uncertainty around SHEDS dose estimation distributions could be better characterized given sufficient data and time. As noted above, collection of additional data or information is likely to help reduce uncertainties and allow for better uncertainty characterizations in the future

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## Appendix A

Other School Data for SHEDS PCB Exposure /Dose Modeling

### Summary

In 2009, Dr. Peter Egeghy of the National Exposure Research Laboratory assembled PCB measurement data at schools and college buildings from various literature and internet sources (shown below). Distributions for PCB concentrations in air, surface wipe, dust, and soil were used to generate input distributions for SHEDS modeling (Figure A-1). All of the SHEDS model parameters and inputs that were used for modeling doses for the three NYC schools using 2010 data were also used for these data.

Results for the estimation of PCB doses across the distribution percentiles were included in Tables 12 – 14 for comparison with the 2010 NYC school results for the 6-10, 11-13, and 14-18 year-old age groups. Overall, the mean and median estimated doses were similar for the two sets of data when comparisons are for the pre-remediation time point for the 2010 NYC school measurements. The estimated doses from the 2010 NYC measurements were somewhat lower than estimates from the other school data at the 95$^{th}$ and 99$^{th}$ percentiles. The fraction of dose resulting from inhalation was higher for the 2010 NYC estimates than for the other school data, largely because the indoor air PCB concentrations in the 2010 NYC schools were about seven times greater (on average) than the other school data. On the other hand, concentrations in wipe samples in the 2010 NYC schools were about one-third (on average) of the levels obtained from the other school data, with the dermal and non-dietary ingestion representing a lower proportion of the intake at the 2010 NYC schools.

### Data Sources

Indoor Air:
UMass Amherst (http://www.ehs.umass.edu/PCB-information.htm)
University of Rhode Island (http://www.uri.edu/news/chafeeclosedfinal.htm)
Coghlan et al., 2002 (http://www.pcbinschools.org/Characterize%20pcb.pdf)
Sullivan et al., 2008
(http://www.trcsolutions.com/Files/File/dioxin2008_Sullivan_Paper.pdf)
Harrad 2007 (http://www.rsc-aamg.org/Documents/Papers/MAA2007/StuartHarrad.pdf)
[Survey of NYC Schools not included because only 1 of 127 samples was above the rather high detection limit of 0.56 μg/m³]

Outdoor Air:
UMass Amherst (http://www.ehs.umass.edu/PCB-information.htm)
University of Rhode Island (http://www.uri.edu/news/chafeeclosedfinal.htm)
Harrad 2007 (http://www.rsc-aamg.org/Documents/Papers/MAA2007/StuartHarrad.pdf)

Dust
UMass Amherst (http://www.ehs.umass.edu/PCB-information.htm)
University of Rhode Island (http://www.uri.edu/news/chafeeclosedfinal.htm)
Coghlan et al., 2002 (http://www.pcbinschools.org/Characterize%20pcb.pdf)
Sullivan et al., 2008
(http://www.trcsolutions.com/Files/File/dioxin2008_Sullivan_Paper.pdf)

Soil
Massachusetts Schools (http://www.pcbinschools.org/Sampling%20Reports.htm)
SUNY Oswego (http://www.pcbinschools.org/Sampling%20Reports.htm)
MIT (http://westgate.mit.edu/node/10)
Herrick et al., 2004 (http://www.ehponline.org/members/2004/6912/6912.pdf)

Wipe
Survey of NYC Schools
(http://www.pcbinschools.org/Caulking%20Survey%20FINAL%204.5.08.xls)
FrenchHill (http://www.pcbinschools.org/Sampling%20Reports.htm)
UMass Amherst (http://www.ehs.umass.edu/PCB-information.htm)
Coghlan et al., 2002 (http://www.pcbinschools.org/Characterize%20pcb.pdf)

## PCB Concentration Distributions

Distributions of PCB measurement results for indoor and outdoor air, surface wipe, dust, and soil samples obtained from the source above were plotted and are shown in Figure A-1. Distributional parameters from these data sets were input into the SHEDS model to generate distributions of estimated doses for comparison with estimates derived from the 2010 NYC school measurement data.

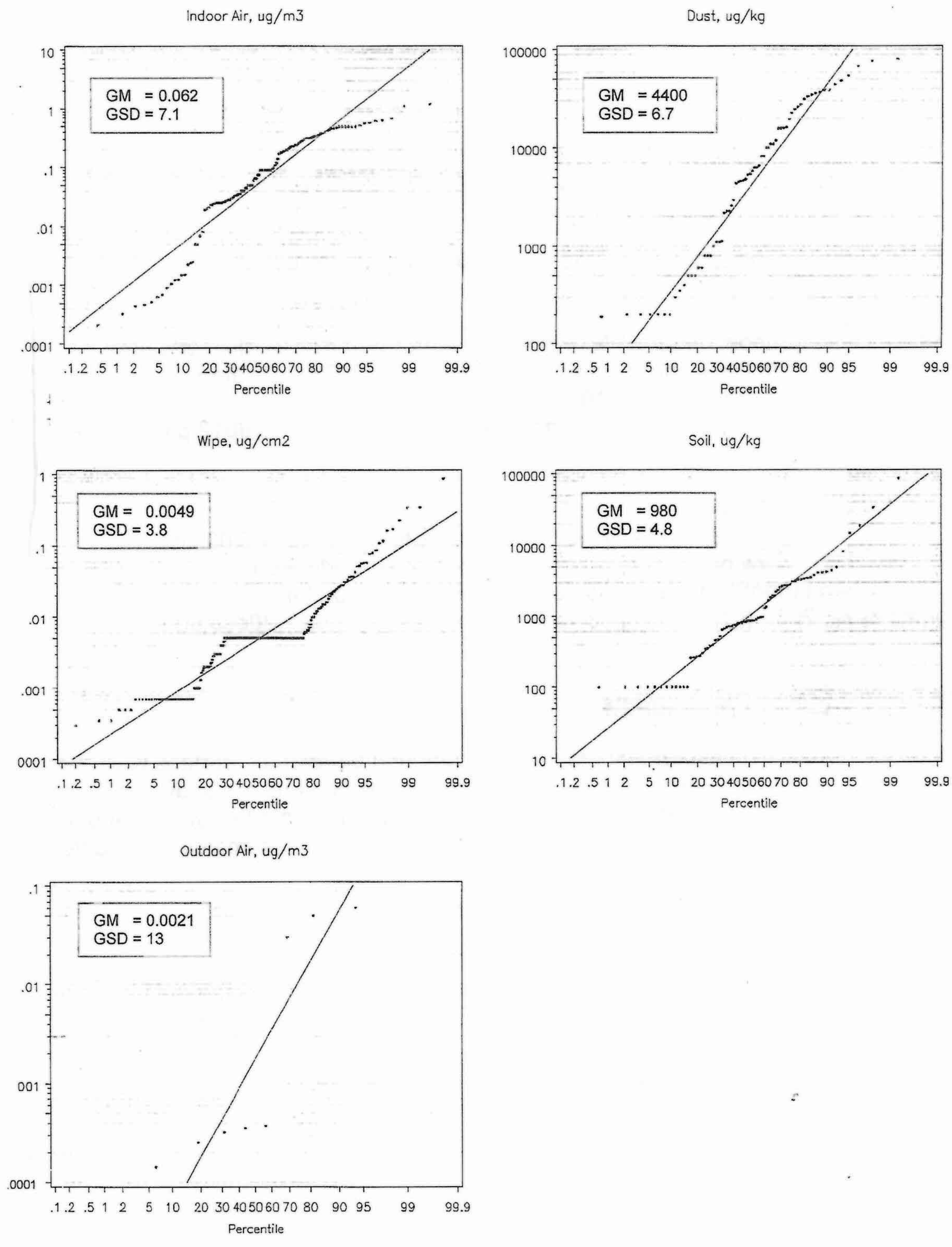


Figure A-1. Distributions of Total PCB Concentrations in Several Environmental Media Collected at School and College Buildings.